DESCRIPTION AND FIRST EXPERIENCE WITH THE RF MEASUREMENT PROCEDURE FOR THE EUROPEAN XFEL SC CAVITY PRODUCTION

A. Sulimov, T. Buettner, A. Goessel, D. Kostin, G. Kreps, W.-D. Moeller, D. Reschke, J.-H. Thie, K. Twarowski, Deutsches Elektronen-Synchrotron, DESY, Notkestrasse 85, 22607 Hamburg, Germany

Abstract

Cavity production for the European XFEL was recently started with first niobium sheets arriving. From this stage to the accelerating module being ready for the linac installation, many critical RF measurements are necessary.

During the mechanical cavity fabrication the cavity half-cells, dumb-bells and end-groups are measured and sorted. The cavity spectrum and field profiles are measured and tuned.

The HOM (Higher Order Modes) couplers filter tuning, vertical cavity RF tests, cavity checks during the string assembly and final cavity performance measurements in the module as well as the fundamental mode and HOM RF spectra measurements complete the sequence.

We present the procedures of the RF measurements and discuss the first results for the XFEL prototype modules with special attention for the cavity tuning.

INTRODUCTION

All cavity production steps will be presented here in the aspect of RF measurements for XFEL superconducting cavities. Table 1 summarizes the sequence of the RF measurements.

Table 1: RF Measurements for XFEL Cavities

Step		Measurements
Cavity	Fabrication	• frequencies of half cells; • frequencies of dumb-bells; • frequencies of end groups; • fundamental mode spectrum.
	Treatment	• fundamental mode spectrum; • field profiles.
	Cold RF Test	• HOM coupler filters characteristics; • fundamental mode spectrum; • Q_0 vs. E_{acc}; • Q_{ext} for cavity probe antenna.
Module	Assembly	• fundamental mode spectrum; • HOM coupler filters characteristics.
	Test	• fundamental mode spectrum; • cable calibration; • HOM spectrum; • Q_0 vs. E_{acc}; • Q_{load} for main input coupler.

CAVITY FABRICATION

The main goal at this stage is the checkout of all cavity parts and sorting the positions of dumb-bells (two half-cells welded in iris region). Cavity length and frequency must stay within the tolerance limits after welding. The influences of chemical surface removal and possible tuning (with a sensibility of 0.3 MHz/mm) have to be taken into account.

The checkout of cavity parts (half-cells, dumb-bells and end groups) implies the measurements of the length and the frequencies. They have to be corrected by reshaping or reducing their length and measured again.

The results of final measurements after the last test are saved in the database. The statistical data in series production are very important and should be observed during cavity production. An example of such an analysis is shown in Fig. 1 for half-cells.

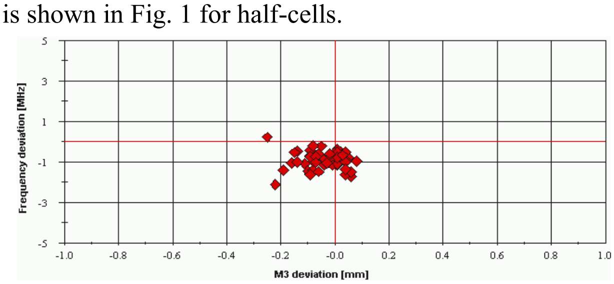
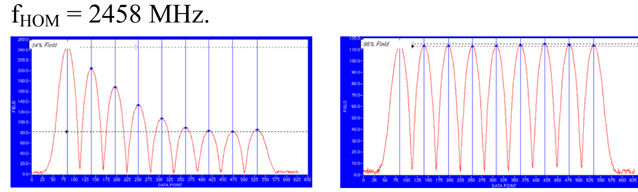


Figure 1: Statistic data for half-cells.

After all dumb-bells have been produced and corrected they should be sorted, to achieve the planed field distribution asymmetry in the fundamental mode (see Fig. 2a). It provides the HOMs amplitudes distribution needed for their effective extraction after the cavity tuning. The example of HOM field distribution for an asymmetrical cavity with two different end-cells is shown in [1] for the highest mode in the pass band f_{HOM} = 2458 MHz.



(a) (b)

Figure 2: Field distribution of fundamental mode TM010 (a) – before and (b) – after the tuning.

To provide the measurements for a large amount of cavity parts for the XFEL project three semiautomatic RF measurement machines HAZEMEMA [2] were designed and built at DESY. This machine decreases the test duration considerably (up to 80 %) compared to manual operation.

CAVITY TREATMENT

All cavities have to be tuned and measured several times before they could be welded in the helium vessel.

The goal of cavity tuning is to achieve the nominal RF (spectrum and field flatness) and geometry (length and eccentricity) characteristics both at once. The mechanical and RF measurements are needed to calculate an effective tuning plan (model).

At this stage up to three tunings could be needed. Cavity conditions differ and depend on the value of the rest planed chemical surface removal, on the existence of the field measurement system (FMS) and on welded rings and bellow for a helium vessel [3]. After each tuning the cavity has to show the corresponding target π-mode frequency with a tolerance of ±50 kHz.

The flatness of the accelerating electrical field on cavity axis – the ratio of the cell with the minimum electrical field and the cell with the maximum electrical field must be greater than 0.98 (see Fig. 2b). Even field distribution with a ratio close to 1 maximizes net accelerating voltage and minimizes peak surface magnetic field.

One of the main RF characteristics after the final tuning is a cavity fundamental mode spectrum. It correlates with the field distribution. After the next stage of the cavity production it is normally in a closed condition with all flanges assembled. Therefore, there is no possibility to measure the field flatness, only the cavity spectrum can be measured.

Four automatic tuning machines [4, 5] for 9-cell TESLA type cavities were designed, fabricated and upgraded within a collaboration of DESY, Fermilab and KEK. Two main achievements of using these machines for the XFEL project are the tuning time reduction from 2 days to 4 hours and non-RF expert operation.

CAVITY COLD RF TEST

From this step on all procedures are carried out by DESY. For the XFEL project the Accelerating Module Test Facility (AMTF) is under construction. All cavities and accelerating modules of the later series production will be tested under operating conditions before being installed into the European XFEL tunnel.

The two main procedures before starting the cold RF test at this stage are comparison of fundamental mode spectra and tuning the HOM coupler rejection filter. They both are made in warm conditions.

As an example a comparison of two spectra for cavity AC158 is presented in Fig. 3. First spectrum is a reference (was measured just after cavity tuning) and second one was measured two months later after a chemical treatment of about 50 µm surface removal and evacuating of the cavity. The relative spectrum graph shows the difference between frequencies ratio of each mode (F - measured spectrum and f - reference one) and ratio of π-mode frequencies. The mean squared error (MSE) is calculated for relative spectrum and its linear fit curve shows the deviation of cavity field flatness. If this value does not exceed 10 kHz and relative spectrum curve stays within the limits (two parallel top and bottom lines in the graph) the field flatness change is less than 10 %.

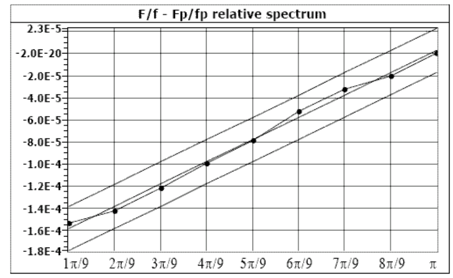


Figure 3: Comparison of spectra for cavity AC158.

The second important procedure is tuning of HOM couplers filter [6]. The goal is reaching the minimum RF transmission on the operating mode (π-mode), normally -70 dB. It is done by changing the gap between HOM coupler antenna end and cap (capacitance tuning) by applying a force (push or pull) on the HOM coupler cap (see Fig. 4) using a special tool. Each cavity has 2 HOM couplers; fundamental mode rejection filter must be tuned on both of them.

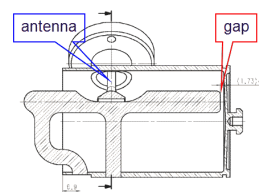


Figure 4: HOM couplers filter tuning.

One of the most important cavity parameters is the maximum accelerating field. It is measured in the vertical cryostat at 2 K.

During this vertical acceptance test the interdependency between the cavity's quality-factor and its accelerating field is measured. An example of such dependences for 8 PXFEL1 module cavities is presented in Fig. 5. The design values for XFEL cavities are an accelerating gradient of 23.6 MV/m at a Q-value of $1 \cdot 10^{10}$.

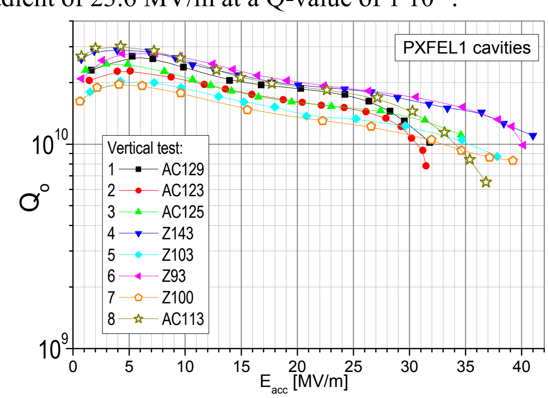


Figure 5: Vertical test results.

One more RF measurement has to be done before the cavity will be installed into the module. Cavity probe antenna Q_{ext} is determined to check the field probe coupling.

MODULE ASSEMBLY

The HOM couplers rejection filters have to be tested and tuned if needed, before the module assembly.

The fundamental mode cavity spectra are compared to corresponding spectra after the last tuning procedure to check for a possible field flatness change.

These procedures were described above. The cavities are filled with argon or dry nitrogen at 1 bar during this stage.

MODULE TEST

The module test procedures including all RF measurements are described in [7].

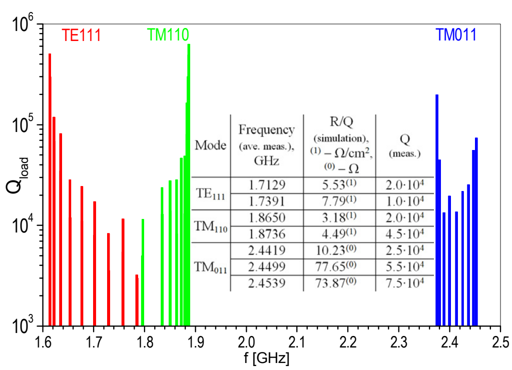
The comparison of fundamental mode spectra for cavities usually is not needed. The π-mode frequency is measured with an accuracy of about 1 kHz during cavity tuning to 1.3 GHz using the motorized cavity tuner.

RF cable calibration at 2 K for both HOM couplers and cavity probe is necessary for the RF power measurement and field probe calibration.

Q_{load} measurements for the main input coupler are done as well. The Q_{load} tuning range is determined, then Q_{load} is set to $3\cdot10^6$ for each of 8 couplers in the module.

The HOM parameters in the XFEL and ILC cavities are described in [8]. The measurements of HOM spectra are being done for two dipole bands (TE111, TM110) and for a second monopole band TM011.

The intense electron bunches excite eigenmodes of higher frequency in the resonator which must be damped to avoid multibunch instabilities and beam breakup. Modes which have high shunt impedance R_{sh} are more dangerous (see Fig. 6).



Mode	Frequency (ave. meas.), GHz	R/Q (simulation), (1) – Ω/cm², (0) – Ω	Q (meas.)
TE_{111}	1.7129	5.53(1)	$2.0\cdot10^4$
	1.7391	7.79(1)	$1.0\cdot10^4$
TM_{110}	1.8650	3.18(1)	$2.0\cdot10^4$
	1.8736	4.49(1)	$4.5\cdot10^4$
TM_{011}	2.4419	10.23(0)	$2.5\cdot10^4$
	2.4499	77.65(0)	$5.5\cdot10^4$
	2.4539	73.87(0)	$7.5\cdot10^4$

Figure 6: HOMs spectrum.

The measurements of Q_0 vs. E_{acc} for cavities in the module at this stage are similar to cold RF cavity test except they are done in pulse mode with 10 Hz rep.rate using the high power pulsed RF source (klystron). The vertical cryostat cavity RF test is done in CW mode, using the RF amplifier. The final test results for the module PXFEL1 (red bars) compared to previous vertical acceptance test results (blue bars) are presented in Fig. 7. The XFEL accelerating gradient goal was reached in this test. With tailored RF power distribution even higher average module gradients could be reached.

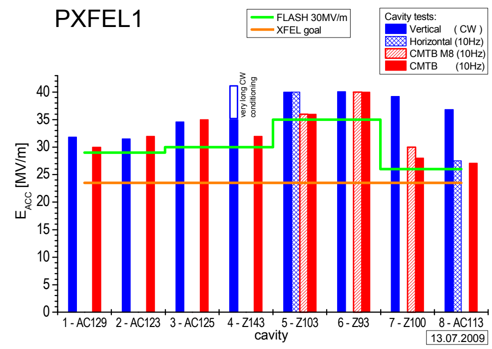


Figure 7: Cavities tests results for module PXFEL 1.

SUMMARY

Series production of more than 800 9-cell TESLA type cavities for the European XFEL project not only requires high quality operation during all stages, but also maximal decrease of duration for each of step.

The new equipment such as HAZEMEMA and new Cavity Tuning Machine allow reduction of the procedures' duration for corresponding RF measurements up to 80 %.

ACKNOWLEDGMENTS

We are thanking all the colleagues from the TTC, XFEL and ILC who made it possible to develop, fabricate, prepare, assemble, test and operate the SRF cavities and XFEL prototype accelerating modules.

REFERENCES

[1] J. Sekutowicz, "Superconducting cavities", CAS on RF for Accelerators, Ebeltoft, Denmark, 8-18 June, 2010.

[2] J. Iversen et al., "Development and Design of an RF measurement Machine for the European XFEL Cavity Fabrication", 14th SRF Conference, Berlin, 2009, p.786.

[3] A. Schmidt et al., "Update on 1.3 GHz cavity weld to helium vessel and application of the FMS", 14th SRF Conference, Berlin, 2009.

[4] J.-H. Thie et al., "Mechanical Design of Automatic Cavity Tuning machines", 14th SRF Conference, Berlin, 2009.

[5] J.-H. Thie et al., "Commissioning and Upgrade of Automatic Cavity Tuning Machines for the European XFEL", 15th SRF Conference, Chicago, 2011.

[6] D. Kostin, "XFEL Cryomodule Assembly: RF Measurements and Tuning", XFEL String and Cryomodule Assembly Workshop, France, 2008.

[7] D. Kostin, "Superconducting Accelerating Cryo-Module Tests at DESY", TESLA Technology Collaboration Meeting, 2011, Milano, Italy.

[8] R. Wanzenberg, "HOMs in the TESLA 9-cell cavity", SPL HOM workshop, CERN, June, 2009; http://pubdb.desy.de/fulltext/getfulltext.php?uid=10761-28626 .